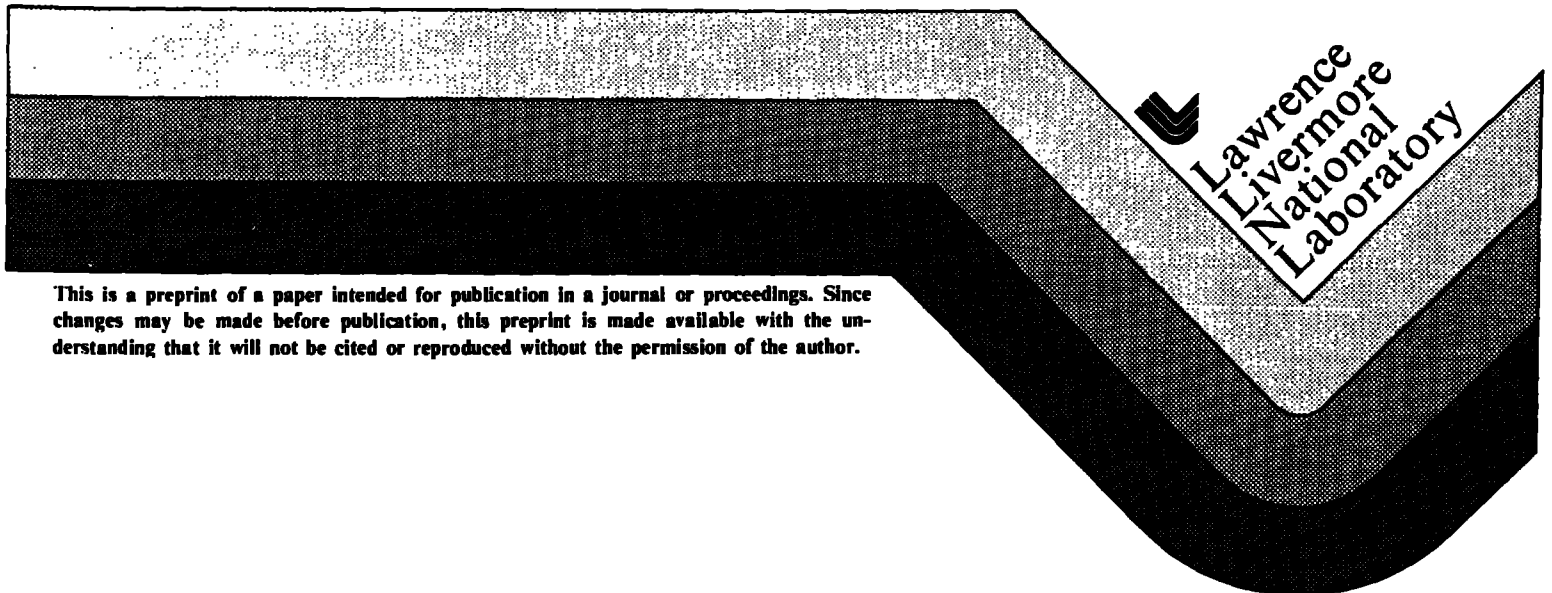


PROTECTING OUR CRITICAL SPACE ASSETS

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Introduction

Over the last 25 years the United States has become increasingly dependent on space-based systems to support its military policies, and this trend is likely to continue for some time. Satellite systems bolster nuclear deterrence by warning of missile launches and providing reliable communications between command authorities and nuclear forces. Satellites also aid in conventional warfighting by providing accurate reconnaissance, weather, and navigation information.

Current and future anti-satellite (ASAT) weapon technologies may be capable of preventing many of our space systems from carrying out their missions, thereby possibly decreasing the stability of nuclear deterrence and weakening the effectiveness of conventional forces. This paper evaluates a broad range of policy options, including unilateral countermeasures and bilateral agreements, that can help to safeguard our space assets. Although most of what follows assumes that space-based strategic defenses are not deployed, the implications of such defenses are explored.

Which Satellites to Protect?

Not all satellites are equally important to our national security, and important distinctions can be drawn between systems. The United States currently performs four types of missions with military satellites that are of interest here:¹

Communications. About a dozen satellites divided among four satellite systems are used for military and diplomatic communications. Except for two satellites that relay messages to the polar regions, all communication satellites are in geostationary orbit (GSO) 36,000 km above the surface of the earth.²

An advanced, interservice satellite communications system called MILSTAR (Military Strategic and Tactical Relay) is now under development, with deployment planned for the early 1990s. It will consist of a half-dozen satellites in inclined geosynchronous orbits, and is intended to provide command and control communications at all levels of conflict, including nuclear war.

Navigation. The U.S. has two satellite navigation systems: Transit and NAVSTAR. Transit, which travels in low earth orbits (LEO) at an altitude of about 1,000 km, was developed to aid in the navigation of Polaris submarines. The much newer NAVSTAR system, when complete, will consist of 18 satellites 20,000 km above the earth. Radio signals emitted from the satellites can be used by special receivers on the earth to obtain very accurate position and velocity information.

Meteorology. Two DMSP (Defense Meteorological Satellite Program) satellites in LEO process visible and infrared images of the earth to provide information on cloud cover, temperature, and precipitation world-wide.

Reconnaissance and surveillance. Under this broad category are several missions that observe electromagnetic signals reflected or emitted from

objects on earth: attack warning, nuclear burst detection, photoreconnaissance, and electronic surveillance. Attack warning is provided by three DSP (Defense Support Program) satellites in GSO that detect the infrared emissions of missiles as they are launched. Sensors on two dozen satellites, including those in the NAVSTAR system, can detect and locate nuclear explosions. Photoreconnaissance and electronic surveillance are highly classified programs, but it can be said that a small number of photoreconnaissance satellites travel in LEO, sometimes at altitudes less than 200 km, to obtain high-resolution photographs for use in treaty verification and intelligence gathering.

Which satellites need protection most, either to maintain deterrence or to perform vital or important functions after the outbreak of conventional or nuclear war? In what cases is it cost-effective to protect the system, and in what cases is it better to perform its mission with earth-based assets (or not perform the mission at all)? Recognizing that the U.S. cannot protect a class of satellites through bilateral agreements while attempting to hold corresponding Soviet satellites at risk, do the benefits from safeguarding the system outweigh the costs of increasing the survivability of corresponding Soviet systems?

These questions are most easily answered when considering systems that are vital to nuclear deterrence, since increasing the stability of deterrence is clearly in the interest of both sides. To the extent that deterrence depends on timely warning, safeguarding attack warning satellites is especially important. Although attack warning is also provided by ground-based radars, satellites can detect missile launches 15 minutes before these

radars, doubling the time available for decisions and relaxing the need for a hair-trigger response.

The ability to communicate orders to the surviving nuclear forces is also essential to deterrence. The weak link in deterrence is probably not the survival of sufficient nuclear forces, but survival of the ability to command them. To the extent that the ability to maintain continuous communication between the National Command Authority and strategic and tactical forces depends on communication satellites (and the geographically dispersed nature of Western forces nearly requires their use), safeguarding these satellites is essential.

Turning to the other military space missions, navigation satellites may be targeted during a nuclear war, so as to deny U.S. bombers and SLBMs accurate guidance information for the destruction of hard targets. This guidance capability is not required to destroy most military, industrial, and population centers. The nuclear burst detection capability may also be a tempting target for the Soviet Union, since it could be used to assess the success of a U.S. strike or the damage from a Soviet strike. But navigation and nuclear burst detection seem to be less vital missions in the maintenance of deterrence.

Meteorological satellites, while very valuable in peacetime and during conventional wars, are less important to nuclear deterrence. Photoreconnaissance satellites are similarly valuable in peacetime to monitor compliance with arms control treaties, and during conventional wars and crises. But they may become threatening during nuclear war since they can

locate surviving forces for retargeting. If necessary, such missions could be performed adequately by aircraft or fractional-orbit satellites in wartime.

So we find that, of the missions performed by satellites now in orbit, attack warning and communications are most essential to maintain confidence in nuclear deterrence. We should on that count endeavor to ensure their survival, perhaps even if, to do so, we must accept agreements that help ensure the survival of the same functions for the other side. Safeguarding these systems should be in the interests of both sides, since increasing confidence in their survivability increases the crisis stability of the nuclear deterrent, thus making preemptive or inadvertent war less likely.

Even though the United States and the Soviet Union may agree that protecting these satellites is stabilizing during peacetime, both countries are tempted to have the ability to destroy them if deterrence fails. For example, attack warning satellites may be capable of locating missile launches accurately enough to tell which intercontinental ballistic missiles (ICBMs) have been fired and which, therefore, are still in their silos and can be targeted. Furthermore, an aggressor is likely to concentrate on the destruction of the command and control systems, including communication satellites, since the number and hardness of these targets is far less than the number and hardness of weapon delivery vehicles. The critical choice here is whether the decreased probability of war from safeguarding these satellites is worth more than the ability to destroy the other country's satellites should war break out. I think that it is.

In the case of conventional war, it is much more difficult to determine

which satellites should be protected. Attack warning, strategic communications, and nuclear burst detection are irrelevant in this case (unless one is planning to escalate the conflict to the nuclear level). On the other hand, tactical communications, navigation, meteorological, and reconnaissance satellites can aid both sides substantially in targeting enemy forces. The latter systems are force multipliers, and both sides will seek to preserve their own capabilities while denying them to the other side.

In what follows, I will focus most of my attention on such nuclear-critical U.S. satellites such as attack warning and communications. It should be noted, however, that technology developed to attack other systems could threaten these critical satellites, although the high orbits of attack warning and communications satellites serve to make attack on them much more difficult, time consuming, and costly.

Soviet satellites. There are three important differences between U.S. and Soviet satellite systems that should be noted here: (a) S.U. satellites have shorter lifetimes, (b) the S.U. has more single-purpose satellites, and (c) the S.U. has a large number of satellites in Molniya orbits. The first two factors combine to give the S.U. a launch rate five times greater³ and a total constellation size nearly twice as great⁴ as the U.S. This does not mean, however, that the S.U. has an advantage over the U.S. in space capability. While it may be true that the Soviets can reconstitute satellite systems more quickly in the event of their destruction by ASATs, it is not clear how valuable this would be (see below).

The fact that many Soviet attack warning and communications satellites

are in Molniya orbits rather than GSO may be very important when designing bilateral agreements. These orbits are highly elliptical, with an apogee (highest altitude) of approximately 40,000 km and a perigee (closest approach) of 500 km. Satellites in this orbit spend over 90% of their time on one side of the earth, where they function like satellites in high circular orbits. But the fact that they come so close to the earth may make them more difficult to protect.

The military uses of space are constantly evolving. The missions described here may become more or less important in the future and entirely new missions may be added that may change the assessment given here.

The ASAT Threat

In the broadest sense, an anti-satellite (ASAT) weapon system is any type of weapon system that can be used to interfere with the mission of a satellite. This includes not only damaging or destroying satellites, but also jamming communications and destroying ground facilities. This paper focusses exclusively on satellite destruction, however, because the latest satellite communications (e.g., MILSTAR) are virtually jam-proof,⁵ and because ground stations can be made much less vulnerable than satellites through proliferation and mobility. This section examines the capabilities of current anti-satellite weapon systems and others that may be possible now and in the future. All of the current weapon systems that have potential or inherent ASAT capability are based on earth. Anti-satellite weapons based in space may be possible in the future.

Earth-based ASATs. ASATs based on earth have the primary advantages of being larger, less vulnerable, and much cheaper to construct and maintain than ASATs based in space. They have the disadvantages of being far from targets in GSO, and of having to cope with the limitations imposed by the earth's atmosphere. The two primary types of ASATs are missiles and directed-energy weapons.

1. Ground-, sea-, or air-launched missiles can be used to attack satellites provided that their range is sufficient to reach the satellite orbit in question. This includes not only missiles intended for ASAT use, such as the U.S. air-launched direct-ascent ASAT now in development or the USSR ground-launched co-orbital ASAT⁶ (both of which are only capable of attacking satellites in LEO), but also nuclear-armed ICBMs and SLBMs and the Sprint and Galosh anti-ballistic missiles (ABMs).

With special changes, such as a lighter payload and proper fusing for ICBMs, SLBMs, and ABMs, or an additional stage for the U.S. ASAT, many of these missiles could deliver ASAT weapons to GSO in the near future. These weapons could be nuclear warheads of various yields or conventional homing warheads. ASATs using nuclear warheads have a damage radius ranging from tens to thousands of kilometers, depending on the yield of the weapon and the hardness of the target satellite. They could damage unhardened friendly satellites. Conventional warheads would have to come much closer to the target—within at least 1 km for a shotgun-type warhead.

The speed of such missiles is about 10 km/s, so it would take at least one hour to reach attack warning and communication satellites at

geosynchronous distances by direct ascent. In the case of conventional warheads, mid-course update and terminal homing guidance are required for adequate accuracy. Although a co-orbital approach is much less demanding in this regard, it also takes at least three times longer than direct ascent. Any attack on GSO satellites with earth-based missiles should be detected by attack warning satellites, since the boosters would be quite large. There could be sufficient time to discover the purpose of the missile and alert the nuclear forces, hence fulfilling at least some of the attack warning and communications missions of the satellites. Because they are slow and detectable, earth-based missiles probably do not represent the most dangerous threat to satellites in GSO.

The situation for satellites in LEO is quite different. Earth-based missiles can reach satellites orbiting 200 to 1000 km above the earth in one-half to two minutes by direct ascent, and guidance technologies have already been proven effective for conventional kill at these distances.

2. Ground-based high-energy lasers (HELs) of certain wavelengths (the atmosphere is transparent to many of the wavelengths between 0.3 and 14 microns) could destroy satellites through heating or shock. They have the advantage of delivering energy at the speed of light (only a tenth of a second is needed to reach geosynchronous distances from the ground) and the disadvantages of being large and inefficient.

Chemical lasers (e.g., deuterium-fluoride), free-electron lasers (FELs), or excimer lasers could be used. It is important to note the differing requirements for damaging one unhardened satellite under test conditions, and

attacking hardened satellite systems effectively. Using favorable assumptions about what may be technically possible, a one megawatt ground-based laser ASAT feasible in the near-term would nearly double the temperature of a satellite in GSO. Most unhardened satellites cannot survive such irradiation. Yet this does not mean that effective ASATs could be based on such lasers.

The power requirements for a real laser weapon system would probably be at least 100 times greater than what is feasible in the near term, in order to compensate for limited dwell time, greater satellite hardness, and other factors. Optical requirements would also be more demanding. To destroy hardened satellites in GSO, ground-based lasers would necessarily thus be very large installations, with power requirements in the hundreds of megawatts. It would probably take several decades to develop such large lasers, and even then it may not be possible to transmit such large amounts of power through the atmosphere without unacceptable beam spreading due to thermal blooming. At least five such lasers located around the world would be needed to provide continuous coverage of all satellite targets.

Satellites in LEO, however, are much less demanding targets. Most could be destroyed by an ASAT system based on the current state-of-the-art chemical laser, although at large costs. Even very hard satellites could be destroyed with lasers that will probably become available in the next decade.

Space-Based ASAT Weapons. Weapons based in space can be much closer to and have a clearer view of the target satellites than earth-based ASATs; hence, for a given level of technology, they can be more effective against satellites in any orbit. Space-based ASATs may be more vulnerable, however,

and the costs of deploying and maintaining ASATs in space is much greater than on earth. Three types of space-based ASAT weapons are explored here: space mines, kinetic-energy weapons, and directed-energy weapons.

1. A space mine is a satellite that is placed in the same orbit as a target satellite, usually well in advance of an attack, which at all times keeps within lethal range of the target. Space mines would also be salvage-fused, meaning that any attempt to interfere with them would cause them to explode, destroying the target satellite in the process. Although no space mines are known to exist, they could probably be developed within a decade.

If conventional warheads are used, the space mine would have to stay within about a kilometer of the target at all times, which may be difficult. Nuclear space mines would be effective at much larger distances (tens or hundreds of kilometers), but they may destroy or interfere with friendly satellites nearby. The use of nuclear space mines during peacetime could lead to an inadvertent war, and their use during a conventional war could encourage escalation. Nuclear space mines are banned by the Outer Space Treaty.

2. Kinetic-energy weapons, either projectiles fired from guns or homing missiles, could be used to destroy satellites by direct impact. Projectiles can be propelled by either chemical reactions (rocket) or electromagnetic energy (rail gun). The primary advantage of using latter is that much higher velocities are possible (over 20 km/s), although current devices are far less capable. A rail gun would weigh hundreds of tons and would not be cost effective unless it could destroy many satellites.⁷

Homing missiles could attack satellites in GSO in several minutes if they are placed in parking orbits within a few hundred kilometers of the target satellite. This differs from a space mine in that the target is normally outside the lethal range. The size and technology requirements of such a missile would be comparable to that of the current direct-ascent U.S. ASAT homing missile, and therefore feasible in the near-term. Such missiles could also carry low-yield nuclear weapons, which would considerably reduce the tracking requirements and be more robust to defensive countermeasures, but would have the liabilities of nuclear use noted above.

3. Directed-energy weapons based in space can use uncharged particles (photons or neutral atoms) of any energy. Charged particle beams cannot be used as ASAT weapons because the earth's magnetic field deflects them. Candidate technologies, none of which are feasible in the short-term, are neutral particle beams, the high-energy lasers discussed above, x-ray lasers, and microwave weapons.

(a) Neutral particle beam (NPB) weapons, which are the best-developed directed-energy weapons suitable for space deployment, are similar to the accelerators used by particle physicists. The particle energy is limited by the size of the accelerator; current design concepts produce particles with energies of a few hundred million electron volts (MeV). Protons of this energy have a range sufficient to penetrate to the center of a satellite and destroy or damage the electronics of current satellites. It may be possible to harden electronics, which would lead to a corresponding increase in the necessary dwell time. Even so, NPBs, if they can be constructed in space, might be effective against satellites in GSO. They are

more effective at shorter ranges, but since NPBs are unlikely to be cost-effective against a single satellite, their use at short ranges is probably limited.

The power requirements for a NPB can be quite large. Depending on the circumstances, over 10 tons of fuel would be required to destroy a 1 tons satellite. An NPB would have a linear dimension of perhaps 50 meters, making it a very noticeable object.⁸

(b) An HEL based in space could make do with a range considerably smaller than an earth-based laser, but as the range decreases so does the number of targets that can be attacked (although the dwell time per target can be proportionately increased). For example, an HEL 1,000 km from a target satellite in GSO would need less than one-thousandth the power of an earth-based laser with the same diameter mirror (space-based mirrors are likely to be smaller), but it could only attack a single satellite, which is probably not cost-effective. Short-range lasers (or NPBs or rail guns) could be put on highly-elliptical orbits that intersect GSO or in counter-rotating GSO, allowing a single weapon to destroy all satellites in GSO, though over an extended period of time (at least 12 hours). For a given range and target hardness, it is very difficult to make a laser smaller and less noticeable, because reducing the size of the mirror increases the power requirements. Even accounting for the increased dwell time, a space-based laser would be quite noticeable and identifiable.

(c) X-ray lasers have the primary advantage of a very compact and extremely high-power energy source: a nuclear explosion. This allows the

possibility that x-ray lasers based in space might not be identifiable, or that they could be put on earth-based missiles and fired as soon as they are above the atmosphere (a few minutes). They would require the launching and exploding of nuclear weapons in space. In theory, they could be very effective ASATs, capable of destroying instantaneously a number of satellites at very long ranges. They are in the research stage and it is not possible to say what can be attained, however.

(d) It may be possible to build a device that uses a nuclear explosion to generate a narrow beam of microwaves. Electronic circuits are probably at least three orders of magnitude more vulnerable to microwave energy than x-ray or particle-beam energy. On the other hand, the destruction of electronics would not usually be noticeable from the outside, leading to uncertainty about disablement of the target. Much more work needs to be done on this concept before further judgments can be made.

In the above discussion, weapon systems size was discussed in terms of their effectiveness relative to U.S. estimates of U.S. satellite vulnerability. Actual Soviet weapons would likely be much more powerful (by perhaps an order of magnitude) for the following reason: for a given threat (x-rays, laser irradiation, bullets, etc.), there is a fairly well-defined threshold beyond which a given satellite system will fail. The defender, who knows the details of the satellite design, can estimate this threshold with some confidence, although there will always be some uncertainty in the estimate of the system's vulnerability; prudence requires that the estimate be lowered, so that one can be confident that the system can survive at this threat level. On the other hand, the attacker does not know the details of

the design, and will substantially overestimate the lethal level required to be confident that the target system will be destroyed.

Possible Countermeasures Against ASATs

Unilateral countermeasures. Unilateral countermeasures are actions that the United States or the Soviet Union can take to safeguard satellites without the cooperation of other countries. Since the ASAT threat is undefined, actions should be taken that are effective against a wide range of technologies.

1. Passive unilateral countermeasures are those that seek to withstand or avoid the attack by an ASAT. These may include (a) hardening the satellite against expected attack (heating, shock, irradiation, and jamming), (b) evasion (maneuvering, hiding, and decoys), (c) redundancy (spares in orbit or ready to launch and land-based back-ups to space-based systems), and (d) moving satellites to less vulnerable orbits.

Hardening can be achieved by some combination of the following: making the working components of the satellite (e.g., solar cells or microprocessors) less vulnerable to the ASAT threat, or surrounding the satellite or vulnerable components by an appropriate shield. Examples of the first type are radiation-resistant electronics to protect against the effects of nuclear weapons or NPBs, or heat-resistant components to withstand laser heating. Examples of shields are multicomponent x-ray shields against nuclear weapons and reflective or ablative shields and sensor shutters against lasers. The measures taken to address one class of threat must be consistent and complementary to those taken for other threats.

These hardening measures can go a long way toward reducing satellite vulnerability, and can also have a favorable cost-exchange ratio against the offense. For example, hardening electronics to levels feasible in the near term (10^6 rad⁹) forces long-range NPB weapons to consume an amount of fuel much more massive than the satellite it is attacking. Decreasing the range of the NPB weapon to make it more lethal would require the construction of additional (expensive) NPB weapons. Another example is hardening against continuous wave (CW) lasers; measures that increase the hardening of satellites by a factor of 10 may cost about 10% of the total satellite costs,¹⁰ but would require a laser 10 times more powerful—and much more costly—to destroy that satellite.

Cost-effectiveness trade-offs are different with regard to hardening against nuclear weapons or kinetic-energy weapons. The cost of nuclear weapons is not proportional to yield: for example, a 10 or 100 kiloton (kt) weapon may not cost much more than a 1 kt weapon.¹¹ Hardening against nuclear weapons can prevent the destruction of more than one satellite by a single weapon, or, in the case of an x-ray laser, decrease the number of satellites a single x-ray laser can destroy. For a given yield, hardening can also force the attacker to come closer to the satellite, thereby increasing warning time and the opportunity for maneuvering.

However, neither a nuclear explosion dedicated to the destruction of a single satellite nor, in the case of kinetic-energy weapons, a direct hit by a 1 kg projectile traveling at a relative velocity of 10 km/s, can be countered by any reasonable level of hardening. It is also very difficult to harden

against the shock effects caused by pulsed chemical or x-ray lasers. For cost-effective unilateral countermeasures against nuclear, kinetic-energy, or pulsed-laser weapons, one must turn to the tactics of evasion and proliferation.

Maneuvering has capability against some threats. For high-altitude satellites, it will work against a nuclear-armed earth-based missile without homing capability. It should also work against terminal homing missiles as long as the satellite can escape the fairly small "basket" or volume of space where the homing system expects to find its target. On the other hand, if the ASAT missile is space-based only 1,000 km from the satellite, the fuel requirements for maneuvering would be excessive. Maneuvering can also be defeated if missiles have a mid-course update capability, and maneuvering doesn't help at all if there is no warning, as would be the case with directed-energy weapons or close-by space mines.

Decoys may be deployed before attack or under attack. If decoys are deployed before an attack, the attacker has time to examine them. The decoys therefore must be realistic and expensive. This cost could be reduced by having a number of spare satellites in orbit that are inactive, and having the decoys mimic these. This is sometimes called "anti-simulation", because one is making the real thing look like a cheap decoy. But even inactive satellites must perform a number of functions, especially if the military is to trust that they would operate properly when called upon. With the time available to the attacker, the defender could never have complete confidence that the decoys were effective. On the other hand, if warning is available, cheap decoys could be deployed at the moment of attack, but this strategy will

only work with non-nuclear homing missiles—ballistic missiles are not smart enough to be fooled by decoys, and directed-energy weapons give no warning.

Another form of evasion is to hide from ASATs, which may be effective against ground-based radar and optical satellite tracking. Even though the current optical tracking system can detect nothing smaller than a one meter-sized object at geosynchronous distances,¹² nearly all satellites require exposed components (antennae, solar cells, etc.) that are difficult to conceal. Space-based satellite surveillance systems that use a larger part of the electromagnetic spectrum could make hiding near the earth all but impossible.

Proliferation is another possibility. If one could increase the number of hardened satellites by a substantial factor, one would, at the very least, force the ASAT system to become large and obvious. But proliferation alone is not cost-effective: if an ASAT system is cost-effective against some number of satellites, it will also be cost-effective against twice that number. The advantage may go to the defense, however, if it is possible to replace complex, expensive, multi-purpose satellites with many simpler, cheaper, single-purpose satellites. This is not the current trend in U.S. satellite design.

A related countermeasure is reconstitution, which is the ability to quickly replace satellites after they have been destroyed. Unfortunately, this is not a practical option for the satellites and time scales that we are most concerned about. Even if replacement satellites were stockpiled (at a cost of several hundred million dollars each), they would take many hours to

launch, and many more hours to maneuver into GSO orbit.

Another potentially effective passive countermeasure is to move critical satellites into higher, less-crowded orbits. These non-GSO orbits have several advantages: (a) ground-based ASATs missiles would take longer to reach higher altitudes, increasing the time available for warning or maneuvering; (b) the power requirements of ground-based laser ASATs is proportional to the square of the satellite altitude, so that a target at 10 times GSO would require a laser power 100 times greater; (c) super-synchronous orbits are not unique as GSO is, making the orbit less crowded and the identification of potentially hostile satellites much easier; and (d) satellites in super-synchronous orbits are more difficult to track from the ground, which can frustrate ASAT attacks.

There are several disadvantages of basing satellites in high orbits. First, the cost and complexity of satellites and ground stations will increase somewhat due to tracking requirements (satellites above GSO orbit more slowly than the earth revolves), and due to the fact that transmitting power and/or receiver sensitivity would have to compensate for the increased distance. Second, the resolution of reconnaissance and surveillance satellites, such as attack warning satellites, decreases with distance. Third, the cost of launching satellites into orbits higher than GSO will be somewhat greater, since up to 20% more energy is required for a given payload mass. Note that the number of satellites necessary to perform a mission need not increase, but that the size, power requirements, and cost of each satellite would probably be substantially greater.

There is time to complete a program of passive countermeasures. Typical U.S. military satellites have lifetimes of 5 to 10 years. Although some current satellites cannot withstand even a relatively mild ASAT attack, there is sufficient time to take unilateral measures to greatly increase the survivability of future systems, since it would take the Soviet Union at least 10 years (and probably much longer) to design, test, and deploy an advanced prompt-kill ASAT capable of threatening critical satellites in GSO.

Passive countermeasures, especially hardening, can go a long way toward lessening the vulnerability of satellites. They also cause effective ASAT systems to become large, expensive, and detectable. They are not sufficient by themselves to ensure survivability, however. There is no perfect passive countermeasure, nor are there perfect substitutes for space assets. Secure, redundant land links would not satisfy all strategic requirements and would be very expensive for the U.S. (but less so for the S.U.). In the case of attack warning, it would mean relying on half the current warning time, or giving up reliance on tactical warning altogether, which would require a new strategic posture.

2. Active unilateral countermeasures are those that threaten the attacking ASAT system. This would mean deploying one's own ASAT to either deter attack or to destroy the opposing ASAT. The latter systems are sometimes called DSATs (defensive satellites), but it is not clear what is the technical difference between systems that are designed to kill satellites and those that kill ASAT satellites. A basis for a valid distinction might be DSAT systems that can only attack over a very limited range and that are associated with a certain satellite system. In this case, DSATs would be seen

as strictly defensive, since they could not attack the opposing ASAT system unless they advanced within range. Although this may be practical against ASAT space mines or missiles, such defenses would be worthless against directed-energy weapons unless the range of the DSAT was at least as large as that of the opposing ASAT.

Self-defense systems could not be added to current satellites, since the weight and power requirements of such systems is likely to be far greater than the satellite it is protecting. In addition, the operation of some DSAT weapons could destroy a nearby satellite. A separate DSAT satellite, very much resembling the ASAT systems described above, would be needed. Destroying a nuclear warhead at a range of 1,000 km, for example, would require a very large NPB or laser. DSAT weapons may not be able to defend the satellite at all if the nuclear weapon is salvage-fused and can be maintained close to its quarry.

Depending on the balance between active and passive measures, space-based ASATs could give an advantage to preempting and therefore be crisis unstable. If both sides depend on satellites to perform crucial deterrence functions, and both sides also deploy ASATs to threaten the other's satellites (as well as their ASATs), then substantial benefits could accrue to the side going first. This is essentially the same argument that is used when evaluating vulnerable land-based ICBMs: if both sides have valuable but vulnerable weapons, each will fear preemption by the other, and will therefore be tempted to preempt. A crisis or accident (collision with space debris) could trigger a satellite war and measurably raise the probability of terrestrial war.

Active countermeasures are also likely to be arms-race unstable for similar reasons. If ASATs are practical, then so are DSATs, which could also function as ASATs, leading to a measure/countermeasure arms race.

These arguments apply especially to space-based systems; if ASATs are earth-based and do not rely on space-based components, then ASATs could not attack other ASATs, and ASAT deterrence may be crisis stable, though it will still add a component to the arms race. An example is the U.S. ASAT under development, which can reach targets anywhere in LEO but cannot easily be preemptively destroyed.

But if ASATs can be made invulnerable to preemption, then DSATs cannot prevent satellite destruction, they can only threaten retaliation in kind. ASAT deterrence may not work, however, if the Soviets valued the destruction of our satellites more than the survival of their own. This may be the case with preemptive strategic attack, where attack warning, communications, and navigations satellites would be much less valuable to the attacker after the missiles are launched, or in the case of a conventional war, in which the U.S. would be more dependent on satellites than the S.U.

Bilateral/multilateral agreements. If both sides have a stronger interest—at least in peacetime—in safeguarding their space assets (or some part of them) than in maintaining a capability to destroy the other side's, and if unilateral measures taken to safeguard these assets force ASAT systems to be expensive and detectable, then verifiable bilateral or multilateral agreements to limit ASAT technologies or deployments may be possible and may

be perceived by both sides to improve the security of both nations. For this to occur, a policy decision must be reached on both sides to the effect that such factors as enhanced crisis stability and decreased arms expenditures outweigh the wartime advantage of holding satellite systems at risk. Indeed, the Scowcroft commission recommended that the U.S. attempt to negotiate agreements to make critical satellites more survivable.¹³

Measures taken unilaterally to make satellite systems survivable will make arms control seem advantageous, both because they serve to increase the cost and decrease the effectiveness of ASAT systems, and also because they drive ASAT systems to larger dimensions and power requirements so that bans and other restrictions are more likely to be verifiable. A variety of restrictions on ASAT development, testing, and deployment are considered here.

1. The testing and deployment of the current U.S. and S.U. ASAT weapons, as well as the testing of other earth-based missiles in an ASAT mode, may be restricted or banned. If the perceived military utility of destroying surveillance and reconnaissance satellites in LEO is great, then both sides may want to keep this ability while banning tests at higher altitudes. One may also choose to "grandfather" existing ASATs because of the difficulty in verifying a ban on their deployment, given that they have already been developed and tested (note that the U.S. ASAT is not fully tested).

Verifying restrictions on ASAT testing may be problematic, however. If ASATs can be successfully tested against a point in space, the other party might not know that a test had occurred, or that the test involved an ASAT weapon. If current low-altitude ASAT weapons are permitted, are low-altitude

tests sufficient to develop a high-altitude ASAT? For example, adding a third stage to the U.S. ASAT might allow it to reach satellites in GSO; one may want to ban modifications of current ASATs to prevent this from happening. The importance of these issues should be resolved before designing a specific agreement.

2. Keep-out zones represent a way to increase the distance between satellites and potential ASATs through formal agreements to maintain a certain separation between the satellites of different nations. An important argument for keep-out zones is that there appears to be only two effective defenses against space mines, whether nuclear or conventional, because of the short range and rapid engagement which is possible. First, any object that could be a space mine would be attacked before it could come within lethal range, an arrangement that is fraught with instabilities. Second, we can try to deal with the problem through the type of agreement proposed here.

As an example of a structured agreement, the United Nations could partition certain zones of space. The most crowded and vital orbit, GSO, is already organized to prevent radio interference. GSO could be divided into 36 zones 10° wide, 12 of which would be assigned to NATO and other U.S. allies, 12 to the Warsaw pact and other S.U. allies, and 12 to neutral or non-aligned countries.¹⁴ This type of agreement has the advantage that only six existing satellites need to be moved. Satellites stationed in the middle of such a zone would be at least 3,700 km from ASATs in an adjacent zone. Even a very large nuclear explosion would not destroy minimally hardened satellites at this distance. Homing missile ASATs stationed at this distance would require several minutes for an attack, allowing sufficient time to assess the threat

and relay a warning message message to earth.

Other orbits could be divided into 72 spherical shells 5,000 km thick starting 10,000 km above the earth and going out to the moon's orbit of 380,000 km, allocated in a manner similar to the 36 zones of GSO. This would include and be consistent with the orbits of NAVSTAR and the Soviet's NAVSTAR-like navigation systems. Space inside 10,000 km and outside the moon's orbit would be unregulated.

Structured keep-out zones may not be acceptable to the world community, however. First, equatorial nations will oppose any measure which gives the use of the space above their nation to some other country or collection of countries. Second, the United Nations current position is that no state can claim space for their own. Keep-out zones may also impose restrictions on satellite missions. It is current practice for satellites to drift several degrees about their mean positions, which would be impermissible at the edges of keep-out zones. Satellites could be kept on tighter orbits, though this would require more fuel.

There are alternative, less rigidly structured possibilities. Spheres of, for example, 1,000 km radius could be agreed to be keep-out zones for certain satellites. Foreign satellites would be prohibited from entering this sphere without permission. This would appear to allow only 130 or so protected satellites in GSO, but the actual upper limit would be several times larger, since satellites of allied nations could be stationed within each other's zones by permission, and since slightly inclined (3°) orbits or orbits somewhat inside or outside of GSO could be used. Such agreements would work

better in semi- or super-synchronous orbits where crowding is less of a problem.

Foreign satellites would be allowed the right of friendly passage, subject to certain restrictions, such as a maximum number of transits per day. Satellites from other nations wishing for some reason to share a keep-out zone could be subject to inspection before launch. Counter-rotating GSO satellites and intersecting elliptical orbits pose a problem and might have to be limited or banned.

Molniya orbits present a special problem for keep-out zone agreements of all kinds, especially because of the asymmetry between the U.S. and the S.U. in the number of satellites in this orbit. Satellites in Molniya orbits come close to the earth—only 500 km at perigee in the Southern hemisphere. The value of keep-out zones is greatly diminished for Molniya orbits, because earth-based ASATs would be much more effective against them. Air-launched ASATs, such as the current U.S. ASAT, can attack these satellites at perigee, since they can be launched from the Southern hemisphere, though to destroy an entire satellite system one would have to wait for all satellites to pass through perigee, which would take up to 12 hours.

3. Bans on testing large (e.g., greater than 1 MW) ground-based lasers in an ASAT mode and on the testing and deployment of large mirrors in space can mitigate the prompt threat from earth-based systems.

4. Many of the remaining prompt ASAT threats, space-based kinetic-energy and directed-energy weapons, could be ameliorated by a ban on their

development, testing, and deployment in space. The testing and deployment of nuclear weapons (and x-ray lasers) in space is already banned. With the exception of nuclear-weapon-driven devices, such a ban should be verifiable since the weapons in question would be large and identifiable, and since they would require testing in space to be reliable, which could be detected.

5. If nuclear directed-energy weapons, such as the x-ray laser, are particularly worrisome, a comprehensive test ban treaty or a low-yield threshold test ban treaty could be negotiated to inhibit their development and testing.

Verification. A variety of technologies can be used to aid in verifying the types of agreements proposed above. Improved space tracking and surveillance systems are usually proposed in connection with ASAT arms control, since they would aid greatly in verifying compliance with keep-out zones, restrictions or bans on ASAT testing, and bans on ASAT deployment in space. These systems can cut both ways, in the sense that a sophisticated space surveillance system can form the basis for an ASAT system as well as safeguard existing satellites, much as large terrestrial radars can form the basis for an ABM system as well as an early-warning system. The ABM treaty prohibited large radars that were not on the perimeter of the nation and looking outward to prevent quick treaty break-out. Just as in the ABM case, the construction of large space surveillance systems may cause concern about compliance with an ASAT treaty.

It may be possible to limit space tracking systems to the mission of verifying compliance with agreements, so that such systems would not be

capable of missions that threaten these agreements. For instance, keep-out zones could be monitored by infrared sensors on board the protected satellite, rather than by extensive networks of dedicated satellites which could easily be the basis of an ASAT weapon. This is a area that should receive more thought.

Space tracking systems can be supplemented by heat, x-ray, and acceleration sensor on-board U.S. satellites could verify that they are not under laser, nuclear, NPB, or kinetic-energy weapon attack. Such sensors are a valuable countermeasure to ASAT warfare with or without arms control.

The deployment of nuclear weapons in space (and therefore nuclear space mines, nuclear homing missiles, and x-ray lasers) is banned by the Outer Space Treaty. At present, it is not possible to verify such a ban. In theory, one could inspect satellites before launch or while in space to detect gamma radiation from the fissile materials. This may or may not be politically practical. The threat from nuclear space mines might be sufficiently defused by keep-out zones, provided that the space surveillance system is sufficiently capable.

The testing of nuclear weapons in space is banned by the Limited Test Ban Treaty. This ban is verified by nuclear-burst detection systems on board current satellites for distances at least out to the moon's orbit. This verification capability could be extended to much deeper orbits by deploying satellites similar to those in the old U.S. Vela system.

Verifying a ban on the testing of ground-based lasers in an ASAT mode is,

in principle, fairly straightforward. As noted above, lasers powerful enough to pose a threat to high-altitude satellites will be very large. The U.S. has shown the ability to locate much smaller lasers. Ground-based lasers are at fixed locations, and can only be tested during cloudless periods, when space surveillance of the lasers is also possible. By posting surveillance satellites over the laser sites, one should be able to detect, by the scattering of light as the beam passes through the atmosphere, whether the laser is being tested in an ASAT mode. In addition, if a comprehensive space surveillance system is available, the optical signals of all large space objects could be monitored, which would make it possible to determine if they were being illuminated by a laser. If necessary, on-site sensors could be placed at large laser installations to ensure treaty compliance.

It is also possible to verify a ban on space-based lasers and particle beam weapons, since such weapons would have to be large and distinctive if sized to attack satellites several thousand kilometers away. Testing of such weapons would be easy to detect by observing their thermal signature, or by detecting effluents given off during their operation. The destruction of satellites by kinetic-energy weapons can also be verified by space tracking and surveillance systems.

Finally, it should be noted that the U.S. must maintain an excellent space intelligence system with or without arms control. In general, it is much easier to detect and monitor certain activities when they are banned rather than widespread. The surveillance technologies necessary to verify the sorts of agreements outlined here are much less ambitious than those envisioned for the strategic defense initiative.

Impact of ASAT Limitations

What impact would the bilateral agreements described (coupled with unilateral actions to make the satellites as survivable as economically practical) have on the military policies of the United States and the Soviet Union? The most obvious effect would be to deny both countries the ability to destroy high-altitude satellites, both those that are essential for deterrence (attack warning and communications), and those that may not be (navigation and nuclear burst detection). The development of new technologies, such as earth-based HELs, would be allowed, but they could not be tested in an ASAT mode. Space-basing of such technologies would be banned altogether.

SDL. The agreements considered in the previous section would impose restrictions on many military missions that are not now performed in space, but could be, such as ballistic missile defense (BMD). A BMD comprised of directed-energy weapon systems that are powerful enough to destroy thousands of missiles during a few minutes (boost phase) or tens of thousands of reentry vehicles (RVs) over tens of minutes (mid-course phase) will almost certainly be a threat to satellites in LEO, semi-synchronous, and GSO orbits. Such systems could be more effective ASATs than ABM weapons: the ASAT mission can be performed at the moment of one's choosing, and satellites are in general softer targets which travel on predictable paths.

It is true that the distances involved in attacking a satellite in GSO are much greater than in attacking a missile: roughly 36,000 km versus 1,000 km (1,000 km is a commonly-assumed orbit for space-based laser battle stations). Since the intensity of a laser decreases as the square of the

distance, the flux at GSO will be over 1,000 times less than that on a booster; since satellites can be made almost as hard as boosters, for equal dwell times satellites in GSO should be safe, even though the system is potent against missiles. The SDIO supports high-orbit ASAT arms control measures, the motivation being that many of the sensors necessary for strategic defense would be placed in high orbits.¹⁵

Dwell times cannot be expected to be equal, however. ABM systems will have to successfully shoot at 1,000 (boost-phase) to 10,000 (mid-course) objects per minute, while ASAT systems would only need to attack at most 100 satellites in a few minutes. (Satellites could be proliferated or send out decoys, but then so could missiles.) In addition, many more laser battle stations can participate in the ASAT attack than the ABM defense: in the ASAT case, nearly all could, while in the ABM case, less than 1/10th could. These two considerations give the ASAT attack at least a factor of 1,000 advantage in dwell time, and nullify the effect of the added distance. In fact, a defense system would probably be more potent as an ASAT since satellites are more difficult to harden than boosters or RVs, and since an attack can usually be coordinated better than a defense and can occur at a time of the attacker's choosing. Earth-based laser ABM weapons should be particularly effective against satellites, since in most such schemes the laser energy is reflected from mirrors in GSO.

Directed-energy systems capable of boost-phase or mid-course ballistic-missile defense would threaten the high-altitude space assets that the agreements discussed above seek to protect. Countermeasures may or may not change this situation. Moving to deep space orbits, for instance, could be

effective. But a defense based on technologies with limited range (small homing missiles launched from space platforms, for example) might not have much effect on satellite systems. The interactions between defenses and space systems security will have to be considered very carefully.

How can satellites be protected in an world of space-based ballistic missile defenses? Obviously, hardening and active defense (shooting back) will become even more important. What role bilateral agreements can play depends a lot on whether or not the transition to such defenses is cooperative, as many members of the Reagan administration insist it must be. If defenses are deployed cooperatively, meaning not only that defenses are viewed as desirable and stabilizing by both sides, but even that technologies or systems may be shared, then there is no reason why both sides cannot mutually agree to limit offensive countermeasures to such a defense, including ASAT weapons. Keep-out zones could become, by agreement, self-defense zones. SDI technologies could be designed so they would not threaten one another with preemptive destruction, and critical satellites could be moved to orbits high enough to avoid the threat posed by these BMD weapons.

If, on the other hand, the transition to defense were not cooperative, then no controls on ASAT weapons seem possible, for the simple reason that ASAT weapons would be a principle countermeasure to space-based BMD components. For every BMD system deployed, the opponent would deploy an ASAT capable of negating it.

Although one cannot protect present and currently planned satellite systems through restrictions on ASATs and deploy a BMD at the same time, this

does not mean that ASAT arms control is impossible while research continues on BMD. Resolution of this question depends on whether demonstrations and field experiments that may of themselves provide some ASAT capabilities are deemed necessary to the BMD R&D program. If, for some significant period of time, these demonstrations and field tests are not deemed necessary, ASAT limitations could in theory at least be agreed on for that period. In the final analysis, however, developing a BMD and ASAT arms control are probably incompatible.

Space as sanctuary. Limiting the threat to high-altitude satellites will create a sanctuary in space to a certain extent. It is possible that this will actually encourage the use of space for military, but non-weapons, systems, since they will be safe from attack. Although it is difficult to foresee examples of this type of behavior, one can imagine that, for instance, a device could be built that could track ballistic-missile submarines from space. Another example might be high-altitude surveillance satellites that would allow look-shoot-look capability. These would represent a clear threat to deterrence, and we would certainly want the capability to destroy such satellites. But it seems premature to forego arms control just because of these theoretical possibilities.

Space debris. A side benefit of a ban on ASAT testing would be the reduction of space debris. The debris accumulating in orbit in the absence of ASAT testing—paint chips, pieces of exploded boosters, etc.—are suspected to have damaged several satellites in the past few years. The risk of collision of a shuttle-sized object with a large (greater than one centimeter in diameter) piece of debris is currently about 1% per year.¹⁶ It has been

estimated that the planned U.S. ASAT tests could double the total amount of debris in LEO.¹⁷ A more extensive ASAT testing program against real satellites might make whole regions of space unnavigable. The problem would become critical if ASAT tests are conducted at high altitudes, since the debris are removed much more slowly—indeed, at geosynchronous altitude, orbits decay only 1 km in altitude every 1000 years.¹⁸ ASATs could be tested against balloons, which might decrease somewhat the amount of debris generated, but not completely, since such balloons are likely to be heavily instrumented.

Conclusions

The attack warning and communications satellites based in geosynchronous orbit are important for the maintenance of deterrence. These satellites are intended to perform vital functions during, or at the outset of, a nuclear war.

Although current earth-based weapons do not pose a threat of prompt destruction to high-altitude satellites, a variety of future technologies could be so employed as anti-satellite weapons. These include more-powerful earth-based lasers, and space-based mines, kinetic-energy weapons (rail guns and homing missiles), and directed-energy weapons (particle beams, optical lasers, x-ray lasers, and microwave weapons).

A variety of passive unilateral countermeasures, including maneuvering, decoys, hiding, proliferation, and especially hardening and deep orbits, can go a long way toward making satellites more survivable and forcing ASATs to become more sophisticated and costly. A vigorous program of passive

countermeasures should be begun, and it should not be delayed by progress in space arms control, since such measures will make agreements more robust. But passive countermeasures cannot by themselves assure survivability. None can prevent the destruction of satellite from, for example, a space mine placed near the satellite or the lethal fluence of an x-ray laser.

Active defense of satellites or of keep-out zones may be able to thwart the emplacement of space mines, but it might not be crisis stable. Each side may fear preemption and require a hair-trigger posture to prevent both satellites and ASAT satellites from being destroyed. Active defense would probably also lead to a measure/countermeasure arms race as each side attempted to make their satellites and ASATs invulnerable to the other's ASATs. In any case, ASAT deterrence through retaliation in kind is not likely to work in a number of war-time situations.

Bilateral or multilateral agreements can play a large role in safeguarding high-altitude satellites. Bans on testing (and in some cases deployment) of new technologies in an ASAT mode can complement negotiated keep-out zones in limiting the threat from earth-based as well as space-based ASATs. Large-scale testing of an advanced ASAT would be observable, so a ban would be verifiable.

Limitations on ASATs are not likely to be compatible with the deployment of a strategic defense with space-based battle stations. Although such battle stations would have to operate over a much larger distance when used in an ASAT mode, the scale of an ASAT attack is so much smaller than that of a missile defense, and so many more battle stations can participate in the ASAT

attack than the missile defense, that a successful BMD (other than terminal or other limited range defenses) would be a potent ASAT. It is unlikely that either country would willingly forego the ASAT option if the other had plans to deploy space-based BMD components, since ASAT weapons may be one of the most effective countermeasures against such a system.

Footnotes

1. For a review of military space systems, see C. Richard Whelan, Guide to Military Space Programs, Pasha Publications, 1984.
2. All 24-hour (geosynchronous) circular orbits are about 36,000 km above the earth's surface, and those that are not inclined with respect to the earth's equator (GSO) hover above the same point on the equator. It is this unique property that causes so many satellites to be located in GSO. For a review of satellite orbits, see Ashton Carter, "Satellites and Anti-Satellites: The Limits of the Possible," International Security, Spring 1986.
3. Space Analysis and Data Division, "Space Computational Center Satellite Catalog," North American Air Defense, April 1982.
4. R. L. Garwin, K. Gottfried, and D. L. Hafner, "Antisatellite Weapons," Scientific American, June 1984.
5. James B. Schultz, "Space System Designs Promote Survival of the Fittest," Defense Electronics, June 1985.
6. Co-orbital ASATs must match the orbital characteristics of the target satellite, which is very time-consuming. The much faster direct-ascent approach is like firing a gun at the satellite, and requires more sophisticated guidance.

7. U.S. Congress, Office of Technology Assessment, Anti-Satellite Weapons, Countermeasures, and Arms Control, OTA-ISC-281, U.S. Government Printing Office, September 1985.
8. Ibid.
9. Ibid. A rad is a unit of radiation dose. A dose of 1,000 rads is fatal to humans.
10. R. Jeffrey Smith, "Space Experts Challenge ASAT Decision," Science, 18 May 1984.
11. One kiloton is the amount of energy released by 1,000 tons of high explosive. A 15 kt weapon destroyed Hiroshima, and most weapons in the stockpile have a yield of a few hundred kilotons.
12. Donald J. Kessler and Shin-Y Su, Eds., Orbital Debris, NASA Conference Publication 2360, March 1985.
13. President's Commission on Strategic Forces, 6 April 1983.
14. Albert Wohlstetter and Brian Chow, "Arms Control that Could Work," Wall Street Journal, 17 July 1985.
15. R. Jeffrey Smith, "Limited ASAT Proposal Gains Backers," Science, 18 May 1984.

16. Kessler and Su.

17. Eliot Marshall, "Space Junk Grows with Weapons Tests," Science, 25
October 1985.

18. Kessler and Su.

